I N V E S T I G A T I O N S

into the

MOISTURE REQUIREMENTS OF GERMINATING SEEDS

by

Rupert Peters

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Approved W. C. Stevens
Department of Botany

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MOISTURE REQUIREMENTS OF GERMINATING SEEDS.

Introduction.

It has long been recognized that a close relation exists between plant life and soil moisture. Common observation showed our ancestors that wilting occurred when the moisture content of the soil was markedly lowered and that death followed when it was long continued, but it remained for the twentieth century investigators to attempt the discovery of the moisture conditions under which the plants could best flourish and those under which they wilted and died, as well as to point out definitely the boundaries between these. But even yet, very little is to be found in the literature concerning the lower limits of soil moisture in connection with plant growth.

This paper is the record of an attempt to aid in the location of the lowest boundary at which plants may be active, and is concerned particularly with the relation of the wilting coefficient of the soil to the germination of seeds. An attempt has been made to answer the question whether seeds can germinate when the amount of soil moisture is so low that plants growing in it wilt and die.

The work was suggested by Dr. Charles A. Shull, then in the Plant Physiology Laboratory of the University of Kansas, now of the University of Kentucky. Most of the actual work was done in the Botany Laboratory of the Northeast High School, Kansas City, Missouri, near enough to be in frequent consultation with Dr. Shull. It is but fitting that an appreciation of his deep interest and kind suggestions be made here. Thanks are also due Professor W. C. Stevens for suggestions and criticisms in the preparation of this paper.

Historical.

Although Sachs(7) recognized a wide range in the moisture content of various soils when plants wilted (from one and five tenths percent in coarse sand to twelve and three tenths percent in a mixture of sand and humus), he made his tests with a single species, the tobacco, drew his conclusions, and then dropped this line of investigation. Few have taken it up since. Hedgcock (4) found t that entire turgid plants of the same species had, at any given age, approximately the same water content, regardless of the differences in the soil or in the conditions under which they were grown. On the contrary, the water content of plants beginning to wilt varies with the soil, being always greater in clay, loess, and saline soils than in loam, humus, and sand. He also found that xerophytes could remove more water from the soil than could mesophytes or hydrophytes; the former removing all but three percent while the second named left in the same soil under the same aerial conditions at least five percent. Clements(3), independently, arrived at a similar condition.

These were the chief contributions until Briggs and Shantz(1) brought out their work on the "wilting coefficient." They proposed the term and defined it as the percentage of water (based upon the dry weight of the soil) remaining in this when wilting had progressed to such an extent that recovery by the plant was impossible even in an approximately saturated atmosphere, without the previous addition of water to the soil. In working out their results they maintained practically uniform conditions; their greenhouse had an average temperature of about 70 F. and the relative humidity was maintained at eightyfive percent. Such changes in these factors as did occur were slight and gradual. A constant temperature for the soils being examined was maintained by a specially-devised water bath in which the containers were set. About twenty different soils were examined, differing widely in all characters, and giving results ranging from one percent in coarse dune sand to over thirty percent in the heaviest types of clay. For plants, over a hundred species and varieties were tried out, so selected as to give a range from extreme xerophytes to hydrophytes. In general, the amount of water remaining in any one of these soils when the plants growing in it had fully wilted, was practically constant. It made no difference as to the plants used, being a fixed quantity for that soil. Furthermore, they worked out formulae by which this wilting coefficient for any soil could be calculated from either of four factors: its moisture equivalent, its hygroscopic coefficient, its moisture-holding capacity, or its texture as determined by mechanical analysis. Their wilting coefficient was the standard when this work was begun. Since then, the work of Caldwell[2] has come to hand. He carried on his experiments at the Desert Laboratory of the Carnegie Institution at Tucson, Arizona. Here, transpiration was excessive as a result of the heat, low humidity, and the hot, dry winds. When he produced conditions similar to those of Briggs and Shantz, his results tallied with theirs. When conditions were natural for his location, he found the wilting coefficient always higher (even thirty to forty percent) than theirs or than that calculated from their formulae. Further, "under any set of aerial conditions, the observed soil moisture content at permanent wilting is approximately a constant for each of the soils used, and its value increases with the increase in the rate of transpiration, being greater under conditions of high evaporation intensity and declining with the decrease of the evaporating power of the air. For a series of plants grown in any soil, and wilted under different aerial conditions, all with relatively high evaporation rates, as many different soil moisture contents at permanent wilting are obtained as there are sets of conditions." Russell[6] has shown that the rate of supply of soil water is simply the speed at which water can move in the soil, and this depends upon the amounts of clay and colloidal matter present. Livingstone[5] calls attention to another factor which complicates the problem still more. In a set of experiments carried on in the Johns Hopkins' greenhouses where he had plants grown with their roots in vessels of water and subjected to various aerial conditions, he found that with the "back pull" of the soil thus cut out, temporary and even permanent wilting occurred. His conclusion is that the trouble is internal, the absorbing power of the roots is inadequate to supply moisture as rapidly as it is lost by evaporation. Hence, he thinks permanent wilting need not depend upon soil moisture conditions necessarily, although it frequently does. Caldwell's higher results are thus evidently due to the rapid transpiration of water from the leaves associated with the slowness of water movement in the soil, especially when the amount present was quite low; in other words, the water was evaporated from the leaves more rapidly than it could be absorbed from the soil, and wilting followed as the result of this "back pull" before the amount of moisture in the soil was lowered to the point reached in the corresponding tests of Briggs and Shantz.

Methods.

Since the purpose of this investigation is to determine if germination can occur with far less moisture than is commonly thought necessary, since transpiration is not a factor in these tests (thus making them somewhat similar to those of Briggs and Shantz in that they had always a high humidity present in theirs), and since the Briggs and Shantz' figures are lower than Caldwell's, they are retained as the standard for this test. Nevertheless, it is recognized that this may not be a fixed standard for all conditions but may vary with differing atmospheric conditions whenever transpiration is a factor.

Because quartz sand and its data were available, it was used. It is designated as No. 2/o by its manufacturers, the Wausau Quartz Company, and passes over a 147-mesh screen but through a 124-mesh one, thus making the average diameter of the particles about 0.1 mm. It contains by analysis

Silicon dioxide	99.07 %
Iron oxide	0.17 %
Aluminum oxide	0.52 %
Hygroscopic moisture	0.06 %
Undetermined	0.18 %
	100.00 %

Its wilting coefficient, as determined at the Biophysical Laboratory of the Bureau of Plant Industry, Washington, D. C., of which Mr. Briggs is Director, is 1.31 %.(8)

Two hundred grams of this sand, roughly weighed, was chosen as the unit, merely because it lacked about three centimeters of filling the common heavy glass tumblers used. The unit of sand was spread upon a glass plate and water to produce the desired percentage of moisture was added from a burette, and thoroughly mixed in with a spatula. Owing to varying humidity conditions in the air during mixing at different times, accuracy was approximate only, but as a rule about twenty percent more water had to be added than was desired when mixing was complete. The wet sand was placed in the tumbler, the seeds were spaced more or less evenly about four centimeters below the surface, and the sand was settled by jarring the tumbler against the table. Enough of a melted paraffin-vaseline mixture (twenty percent of vaseline in paraffin having a melting point of 45 C.) was poured over the surface to seal it effectively, and the labelled tumbler was set aside at room temperature for two weeks. As sufficient growth did not occur for photosynthesis to become a factor, light was disregarded.

In this connection, it should be stated that the first set of tests, some thirty, failed because the seeds were planted about a centimeter only below the surface of the sand. The clue was found when a soil sample was taken from the top and another from the bottom of the sand at the close of one of the tests, run for moisture content, and compared. That from the bottom showed a higher moisture content than did the upper one where the seeds were. A series was then run upon a tumbler machine (the one described by Shull, Bot. Gaz., 62:10-11). The bottles were half filled with wet sand, the seeds were added, heavily shellaced corks were sealed in place, and the bottles fixed upon the wheel of the machine so that they had fifteen complete rotations a minute. This so mixed the contents of the bottles that there could be no question as to a varying moisture content in the various parts of the soil mass. The results were checked with another series in which the seeds were planted near the centre of the sand mass, the tumblers sealed as usual, and set aside for the regular time. As results corresponded closely, the more troublesome machine method was not further used.

While filling the tumbler, a carefully chosen sample of the sand was placed in a tared weighing bottle and this was immediately covered. Although this sample was taken when the tumbler was half filled, and although all speed commensurate with careful work was used, yet on dry days considerable loss of water must have occurred from the sand not yet in the tumbler and from the surface of that already in it. This sample was carefully weighed upon a standard balance sensitive to one ten thousandth of a gram and was then placed with cover removed in a drying oven at 100 to 104 degrees Centigrade until a constant weight was obtained. Another source of error is to be noticed here. The particles of dry sand were so light that unless extreme care was used in covering and uncovering the bottles, some of these particles would be carried out on air currents and so give false results in subsequent weighings. From the two figures obtained by these weighings, the percent of moisture in the corresponding sand was obtained.

At the end of the two-week period, the seal was broken and the contents of the tumbler were dumped upon a glass plate A sample was taken quickly for determining the moisture content. Germination was noted and the seeds were separated from adhering sand grains by being gently brushed with a camel's hair brush, were at once dropped into a weighing bottle, and their loss of water then determined by weighing and drying to a constant weight.

Seeds were considered to have germinated when a half centimeter of the rootlet extended through the seedcoat, and to be "incipient" when a shorter length was to be seen: this is another arbitrary standard, but some such point had to be chosen.

It is realized that with no means available for controlling the soil temperatures during the tests, considerable error may have crept in, but with all allowance for such in the results following, it is felt that it would not alter the conclusions drawn.

Preliminary Tests.

An early step taken as a guide to the amount of absorption to be expected was to determine the approximate curve of water absorption of various seeds when conditions were favorable for germination. It was thought that this might be used in comparison with results obtained in the tests as an indicator, suggesting nearness of approach to the necessary amount of water to be furnished. Although of little assistance in the way planned, the results later obtained tallied fairly closely. To get these, weighed seeds were placed upon wet sand, or on or between pads of wet cotton, in Petri dishes at room temperature (averaging 19.5 C.) and weighed at intervals until germination had taken place. The results of one series are shown in Table I. Five such series were run to check results and the variation was very slight in the end results. The series chosen to tabulate here is representative in every respect.

Table 1. Water Absorption in the Germination of Corn.

Test No.	1		2		3		4	
Dry wt.	3.6270		3.7286		3.6565		3.5170	
Time in hours	Gain		Gain		Gain		Gain	
	Grams	%	Grams	%	Grams	%	Grams	%
1	.2731	7.52						
2					.2690	7.3		
3	.3991	11.00						
4			.7215	19.3			.2496	7.0
5	.4926	13.58						
7	.5903	16.27			.5757	15.7		
8			.9848	26.4			.4146	11.2
9	.6585	18.15						
24	1.0119	27.89	1.4463	38.8	1.0834	29.9	.7241	20.5
28	1.9495	28.93	1.5142	40.0	1.1766	32.1		
32	1.1109	30.62	1.5652	41.1	1.2322	33.7	.8809	25.0
48	1.2587	34.70	1.8168	48.7	1.4037	38.3	1.0030	28.5
52	1.3111	36.14			1.4264	39.0		
56	1.3137	36.22			1.4548	39.7		
72	1.4735	40.7			1.5937	43.5	1.1198	31.8
96	2.0045	55.2			1.7588	48.1	1.2073	34.3
120							1.4661	41.1

Number 1 was on pads of wet cotton, all seeds germinated, rootlets averaged two centimeters.

Number 2 was between pads of wet cotton, results as in the first.

Number 3 was on sand to which ten percent of its weight in water had been added; ninety percent germinated, rootlets averaged one and eight tenths centimeters with shoots beginning to appear.

Number 4 was on sand to which five percent of its weight of water had been added; ninety percent germinated as in Number 3.

Table 2. Water Absorption of Legumes.

	Peas		Navy Beans		Soy Beans	
Dry wt.	3.3909		2.7181		4.0166	
Time in hours	Gain		Gain		Gain	
	Grams	%	Grams	%	Grams	%
1			1.0070	40.49	.4811	11.97
3			1.6225	59.69	.8870	22.08
4	2.8367	83.6				
5			1.9493	71.71	1.2667	31.53
7			2.1184	77.93	1.6510	41.10
8	3.9282	115.8				
9					1.9613	48.80
24	5.1386	151.5	2.5903	95.29	3.8499	95.84
27			2.6135	96.15		
28	5 2918	153.1			4.2329	105.38
30			2.6394	97.10	4.4170	109.96
32	5.3788	158.6			4 5323	112.83
48			2.8475	104.76	4.7940	119.35
52					4 8430	120.57
54			2.9528	108.62		
56					4.8823	121.55

All were between pads of wet cotton. The peas and navy beans had perfect germination, the soy beans ninety percent.

The results shown in Tables 1 and 2 are expressed graphically in Figure 1.

Widtsoe[10] gives the following as the percentages of moisture contained in seeds at saturation; wheat, 52 to 57 percent; corn, 44 to 57 percent; peas, 93 percent; and beans, 88 to 95 percent. The averages of five series run here for corn and three each for beans, wheat, and peas were: corn, 43 percent; beans, 108.3 percent; wheat, 69.1 percent; and peas, 149 percent. The differences

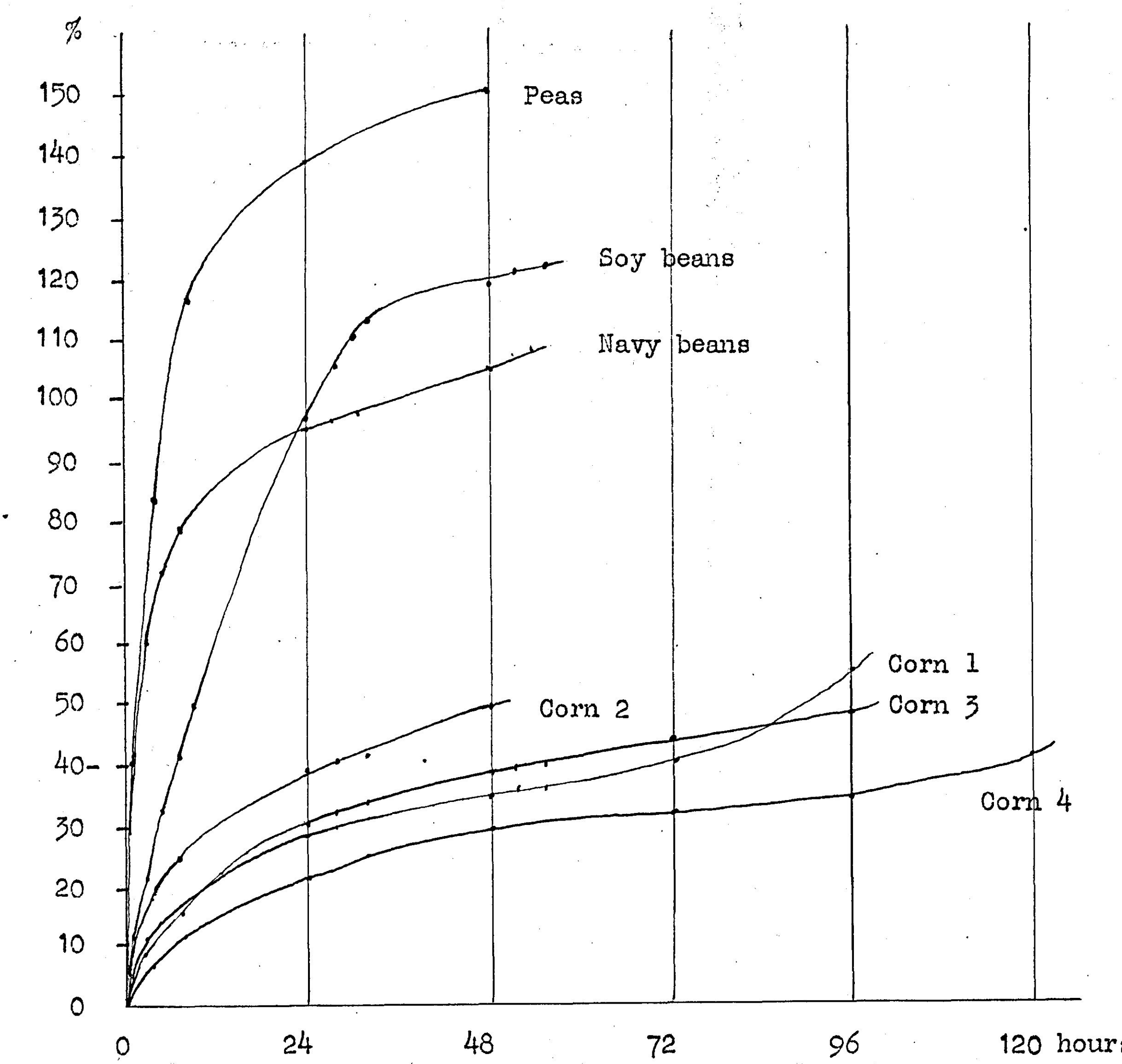

Fig. 1. Water absorption of various germinating seeds. Corn 1 on wet cotton; Corn 2, between pads of wet cotton; Corn 3, on sand wet with ten percent of water; Corn 4, on sand wet with five percent of water; Peas, between pads of wet cotton; Navy beans, hilum down on wet cotton; Soy beans, on wet cotton.

between these and those of Widtsoe are probably due to differing end points or to different varieties of corn and wheat which may have different saturation percentages. The original papers to which he refers are not available. The results reached here will be used as the same end point and seeds from the same lots were used as in the tests following.

Results.

At the same time this preliminary test was run, careful germination tests were made of different lots of seeds and only those were chosen which gave a high percentage of vitality. Corn was the first used, Boone County White as to variety. With no arrangement to keep temperatures down, and working at first in July in a room where it at times became exceedingly warm, a number of early tests failed because the vapor caused the seal to buckle and loss of moisture resulted. The unnoticed loss of sand particles in removing covers when placing bottles in the oven, caused on one series alone some seventy useless weighings in the endeavor to secure constant weights. But when the difficulties had been overcome, results were secured as shown in Table 3, the first ones naturally being too high.

Only those tests are quoted which may be of assistance in reaching conclusions. By "weight of bottle" is meant the tare

Table 3. Results of tests with corn.

No	Weight of bottle	Weight with wet sample	Weight with dry sample	Loss of water	Weight of dry sample	% of water	Germination
22	15.1972 14.9436	27.2665 24.4012	27.0445 24.3547	0.2220 0.0465	11.8473 9.4111	1.87 0.48	All sprouted; tumbler filled with tangle of roots; two shoots through seal.
23	14.9436 13.1033	26.2905 22.4946	26.1013 22.4467	0.1892 0.0479	11.1577 9.3434	1.69 0.51	Four growing vigorously, 25 cm. roots freely branched, no shoots, one rot.
24	13.4485 11.2461	22.8234 21.7644	22.6711 21.6932	0.1523 0.0712	9.2226 10.4471	1.65 0.68	Four germinated, one incipient.
25	11.2461 13.4485	19.7670 22.9802	19 5860 22.9190	0.1810 0.0612	8.3399 9.4705	2.17 0.64	All growing freely, shoots appearing.
28	14.9436 11.2461	27.1611 20.6403	26.9926 20.5776	0.1685 0.0627	12.0490 9.3315	1.39 0.67	All germinated with roots 0.5-3cm., shoots forming.
29	15.7069 13.1033	28.8811 21.4845	27.7170 21.4264	0.1641 0.0581	12.0101 8.3231	1.36 0.69	All with branched roots 5-12 cm., 1-3 cm. shoots.
30	15.1972 13.4485	26.4334 23.1298	26.2708 23.0806	0.1626 0.0492	11.0736 9.6321	1.46 0.51	Four with 1 cm. rootlets, one incipient.
33	14.9436 12.7311	27.2533 21.9564	27.0783 21.8662	0.1750 0.0902	12.1347 9.1352	1.44 0.98	All with 1 cm. rootlets
34	15.7069 11.2461	27.4449 21.7802	27.2634 21.6694	0.1815 0.1108	11.5565 10.4233	1.59 1.06	All with 4-7 cm. rootlets shoots just showing.
36	15.1972 13.1033	26.6290 22.6704	26.5158 22.6056	0.1182 0.0648	11.3186 9.5023	1.00 0.68	One with 2 cm. root and shoot showing, 4 with 1 cm. rootlets.
38	15.7069 15.7069	27.0591 27.1975	26.9420 27.1318	0.1171 0.0657	11.2351 11.4249	1.04 0.57	One fully germinated, 4 incipient.
39	12.7311 12.7311	23.0582 22.4594	22.9908 22.4195	0.0647 0.0399	10.2597 9.6884	0.65 0.41	All swollen.
41	14.9436 13.4485	28.0634 23.8692	27.9723 23.8295	0.0911 0.0397	13 0287 10.3810	0.69 0.38	One with 2 cm. root, one incipient, three swollen.
42	15.1972 13.1033	26.2167 21.9365	26.1267 21.8895	0.0900 0 0470	10.9295 8.7862	0.82 0.53	Two with 1 cm. roots, one incipient, twp swollen.
43	15.1972 13.4485	27.2890 22.8073	27.2100 22.7795	0.0790 0.0278	12.0128 9.3310	0.65 0.29	All swollen.
46	11.2461 12.7311	21.7230 22.8293	21.6416 22.8028	0.0814 0.0265	10.3955 10.0717	0.78 0.26	One with 1 cm. root, the others swollen.

of the weighing bottle in which the particular sand sample was placed for drying. "Weight with wet sample" is the weight of this bottle and the wet sand sample before going into the oven. "Weight with dry sample" means the weight of this bottle and the sand when a constant weight had been secured by drying. "Loss of water" is the difference between the two just given. "Weight of dry sample" is the net weight of the sand sample after drying. "% of water" = $\frac{\text{Loss of water}}{\text{Weight of dry sample}}$. The upper line of figures in each case is the record of the sample taken at the beginning of the test, and the lower one, that at the close.

Navy beans were next tested. Because of their larger size and because they absorb at least their own weight in germinating, (Table 1 and Fig. 1), but two seeds were used for each test lest the necessary moisture demands for germination should so exceed the amount furnished in the sand that germination would be impossible. The results are shown in Table 4.

Table 4. Results of tests with navy beans.

No	Weight of bottle.	Weight with wet sample	Weight with dry sample	Loss of water	Weight of dry sample	% of water	Germination
58	12.7311 15.1972	21.7195 27.7559	21.6582 27.7136	0.0613 0.0423	8.9271 12.5160	0.68 0.33	One somewhat swollen, the other with 2 cm root.
59	14.9436 13.1033	26.5169 22.0372	26.4262 22.0058	0.0907 0.0314	11.4826 8.9025	0.79 0.35	One with 1 cm. rootlet, the other with 0.4 cm.
60	15.1972 12.7311	27.1102 22.0474	26.9874 21.9928	0.1228 0.0546	11.7902 9.2617	1.04 0.58	One with 2.4 rootlet, The other with 0.2 cm.
61	15.7069 13.4485	27.1330 24.1932	26.9881 24.1025	0.1449 0.0907	11.2812 10.6540	1.28 0.85	One with 3 cm. rootlet, one dry and unswollen.

Numbers 59 and 60 are particularly interesting as they show germination of both seeds with amounts of water supplied well below the wilting coefficient of the sand. Number 61, unfortunately, had a dead seed. As a further check in this series, the beans were weighed when selected, again when the test was complete, and were then dried and the loss of water determined. In the table following "Calculated absorption" is based upon the results shown in Table 2 above. The actual loss of weight is in every case below the calculated absorption, even though it includes the moisture originally present in the seeds. This either indicates that germination can take place with less water than the amounts indicated there, or illustrates the difficulty in making transfers without the loss of water, probably the latter. Yet Corn 4 compared with Corn 3 in Table 1, given originally five percent and ten percent of water in the sand, seem to bear out the former idea since the absorption was 41 percent and 48 percent respectively.

Table 5. Loss of water in drying germinated beans.

No.	Original weight	Sprouted seeds	Dried seeds	Loss of weight	Calculated absorption
58	0.5082	0.8624	0.4200	0.4424	0.5448
59	0.5618	0.9484	0.4622	0.4862	0.6067
60	0.5440	1.0178	0.4356	0.5822	0.5875
61	0.5257	0.8092	0.4634	0.3458	0.5677

The final series upon which a report can be made was run with wheat, ten grains to the test. The results follow in Table 6.

Table 6. Results of test with wheat.

No	Weight of bottle	Weight with wet sample	Weight with dry sample	Loss of water	Weight of dry sample	% of water	Germination
101	14.9436 14.9436	28.5618 25.8592	28.4282 25.7821	0.1336 0.0771	13.4846 10.8385	0.99 0.71	Five with 0.5-1.2 cm rootlets, 4 incipient, 1 dead.
102	11.2461 15.7069	21.2021 27.1988	21.0792 27.1070	0.1229 0.0918	9.8331 11.4001	1.25 0.80	Six incipient, 4 unchanged.
103	12.7311 12.7311	24.2885 22.9414	24.1628 22.8613	0.1257 0.0801	11.4317 10.1302	1.09 0.79	Seven with 5-7 cm rootlets, 3 incipient.
104	15.5137 15.1972	24.7871 25.9985	24.6767 25.8904	0.1104 0.1081	9.1630 10.6932	1.20 1.01	Two with 0.5-1.2 cm rootlets, 7 incipient, 1 dead.

Of these, Number 103 gives illuminating results, with Numbers 101 and 104 close seconds.

Discussion.

Some interesting things are shown in these tables. Numbers 22-35 started with moisture contents above that of the wilting coefficient of this sand, 1.31 per cent, the remaining ones quoted were below it. Numbers 36, 38, 59, 60, and 193 show satisfactory germination in a soil given less than the wilting coefficient of moisture. Others come very close to this: they were not listed simply because fewer of the seeds germinated. Some are very suggestive: Numbers 28 and 29, for example, fully germinated and with original moisture contents but 0.08 and 0.05%, respectively, above the limit. There seems abundant evidence in the results shown here to indicate that seeds can germinate at or below the wilting coefficient of the soil.

Why germination did not take place in some instances is still a problem. For example, in Number 4, with 1.55% of moisture on the start, the seeds became slightly swollen with one rotted, and 1.30% of moisture remained in the sand at the close of the test. In the light of the other tests, it hardly seems that five infertile seeds were selected for this particular one.

Further, germinating seeds pull the moisture content to surprisingly low figures, the averages as already given being 0.584% for corn, 0.42% for beans, and 0.83% for wheat. This evidently depends considerably upon the rapidity with which water moves through the soil, as referred to above. In this connection, while Briggs and Shantz found the same amount of moisture remaining in the soil at permanent wilting regardless of the kind of plants grown in it, results shown here show the contrary, as just pointed out. Of course their plants had root systems distributed through the soil and with very short distances, comparitively, to pull the water, transpiration was going on, and wilting gave a more or less definite end-point, while here, there were practically no roots, just as many absorbing centres as there were seeds. There was no transpiration to be a factor, and the end-point was but approximately fixed, making this problem really in no way comparable to theirs. Yet, in a series from the corn tests where the moisture supplied was above the wilting coefficient, there remained at the close of the tests, 0.48, 0.51, 0.68, 0.67, and 0.51 percent respectively, which really do not vary a great deal, considering the crude apparatus used, the lack of temperature control, and the variations in the end-points reached.

But, in contrast, in those tests which started with just about this amount of water, the corn grains showed absorptive power sufficient to pull the water down to 0.29, 0.38, and 0.41% respectively. Dead plants, as shown in the work done by Briggs and Shantz (1), would have done this, or more, if extending through the wax seal, but here it went into the seeds. Shull (8) has pointed out in his graph reproduced below, that the soil forces tending to retain moisture increase enormously as the soil becomes drier and drier, especially when approaching air-dry conditions. In these three instances there is shown a tremendous absorptive power which is evidently not present in the six cases given above, or they would have pulled more moisture from the sand.

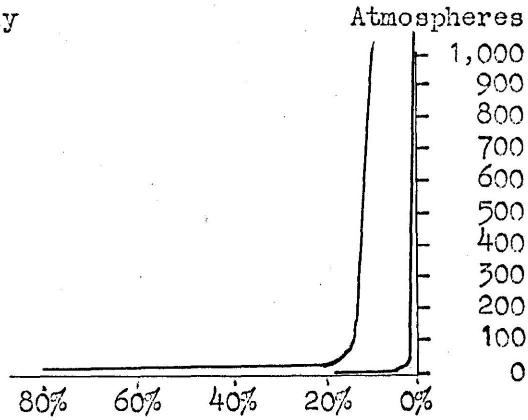

Fig. 2. Curves showing increase in the surface forces of soils as drying proceeds: to the left, Oswego silt loam; to the right, No. 2/o sand.

But Shull (9) also found that airdry seeds of the cocklebur (hygroscopic moisture 7%) had an internal attractive force for water of 965 atmospheres, or over 14000 pounds per square inch, and that when these seeds had absorbed an additional 7% of water this force had dropped to less than 400 atmospheres. The absorptive force shown by the three instances referred to in the preceding paragraph seem to bear out his findings. In the case of the other six there was evidently sufficient water in the sand to allow equilibrium to be teached between the opposing external and internal forces before the percentage of water present was pulled to the low figures reached by the other set.

Another way of looking at the last results mentioned above, Numbers 39, 41, and 43 were given about the same amounts of water each, practically half that required for the wilting coefficient of this sand, and the results are practically the same. By calculation, disregarding that removed in sampling, each tumbler contained a total water content of about 1.3 grams. Of this the seeds absorbed about half, 0.48, 0.62, and 0.72 grams, respectively. According to Table 1, 41% of the weight of the corn seed is the minimum for fair germination when conditions are favorable. Fortyone percent here is 0.73 grams. The maximum used as shown in the table is 55%, or, that would be here, 1.00 gram. With 0.48 to 0.72 grams of water used in these cases, with 0.73 to 1.0 grams used when conditions are favorable for absorption, with the weight of the seeds practically the same, and with the moisture content of the soil pulled down to 0.29-0.41%, it would seem that when the lower limit of possible water absorption from the surrounding soil was reached by the seeds in the cases quoted, they had been unable to secure water enough for germination. The lower limit is probably about 0.75 to 0.85%.

In comparison, Number 36 used but about 0.64 grams of water for complete germination, and when germination was complete, as much water remained in the sand as each of the three mentioned had to start with. But why should Number 36 germinate when it absorbed 0.64 grams of water and Number 43 fail to do so when it absorbed 0.72 grams? Has the rate of absorption or the amount of water remaining in the soil anything to do with these results?

Conclusions.

1. Seeds can germinate when supplied with amounts of water which are below the wilting coefficient for the particular soil used.

2. A uniform water content remaining in a soil when permanent wilting occurs in plants growing in it, regardless of species, does not hold true for seeds germinating in such a soil, even when the amount supplied could have been used in germination.

3. While the amount of water used by seeds for germination may be more or less constant when moisture is abundant, they may germinate with far smaller quantities when the supply is scanty.

4. When the supply of water is scanty, the time for germination is correspondingly lengthened.

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Army service interrupted this work and it is not now convenient to resume it. Its imperfections are realized, but it is hoped that it adds something to our knowledge in this field and that it may suggest questions for further investigation.

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